

# Tomography of the Inner Magnetosphere

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# Topics

- Tomographic Inversion.
- Description of Parameters.
- Systems of Linear Equations.
- Forward Calculation and Inversion.
- MPA-Data Inversion.
- The Geosynchronous Region.
- The Near-Earth Region.
- Summary.

# Tomographic Inversion

- General purpose: Make inferences about physical systems from remotely sensed data.
- Application: Determine neutral hydrogen density distribution in the inner magnetosphere from:
  1. Average proton fluxes measured by the Los Alamos geosynchronous spacecraft.
  2. Global drift pattern calculated from simple electric and magnetic field models.
  3. Assumption: Flux attenuation is caused by charge exchange.



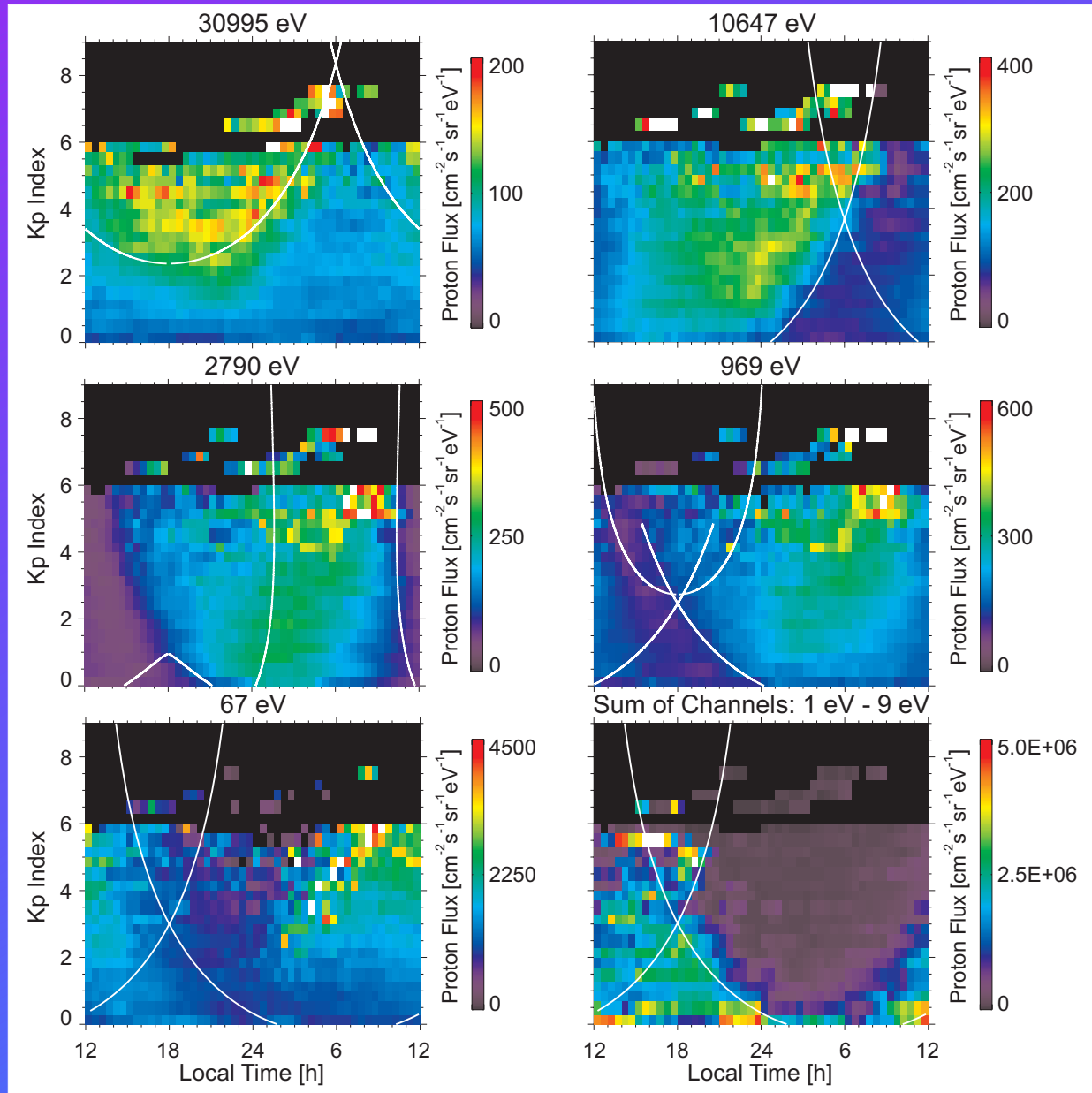
## The Database

(c.f., Korth et al., JGR, 104, 25047–25061, 1999)

- Three Los Alamos geosynchronous satellites: 1990-095, 1991-080, and 1994-084.
- Magnetospheric Plasma Analyzer (MPA).
- Energy range:  $1 \text{ keV} \lesssim E_p \lesssim 40 \text{ keV}$  binned by local time and Kp.
- Spin-averaged fluxes.
- Years included: 1996, 1997, 1998.
- Number of 10-sec. measurements:  $\sim 1$  million / year.



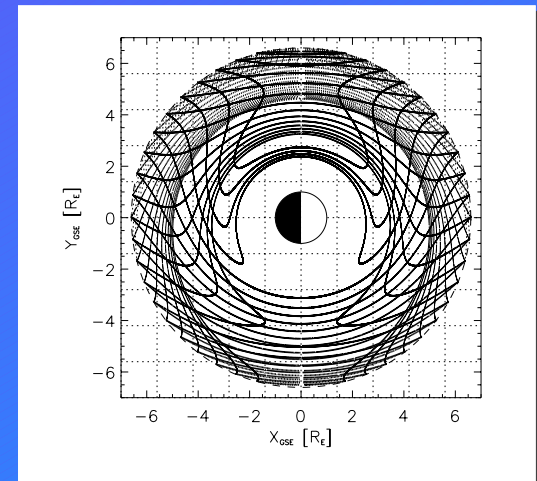
# Proton Flux Statistics 1996



from Korth et al., JGR, 104, 25047–25061, 1999.

# Global Drift Pattern

- Dipole magnetic field:  $B = \frac{c}{r^3}$ .
- Volland-Stern electric potential:  $U = -\frac{a}{r} - br^\gamma \sin \varphi$ .
- Cross-tail electric field strength  $b$  can be parameterized by Kp.
- Drift paths depend on energy, location, and Kp.
- Combination of drift paths leads to a fine mesh of trajectories sampling the inner magnetosphere.
- Only open drift paths are considered.

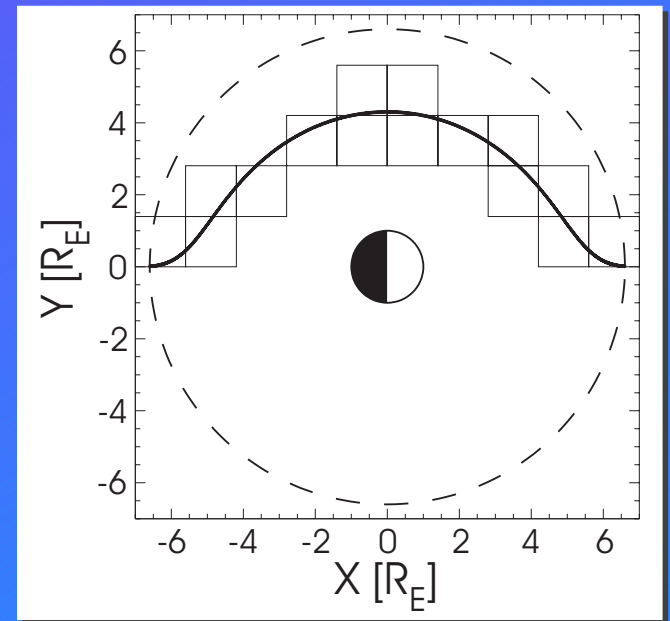


# Charge Exchange

- Process:  $\text{H}_\text{E}^+ + \text{H} \rightarrow \text{H}_\text{E} + \text{H}^+$ .
- Flux attenuation:  $j_\text{out} = j_\text{in} \exp \left( - \int \alpha \, dt \right)$ .
- Discretization.
- Charge exchange loss coefficient:  $\alpha = \sigma \, v \, n_\text{H}$ .

$$\Rightarrow \underbrace{\sum_i \sigma_i v_i \Delta t_i}_A \underbrace{n_{\text{H},i}}_{\vec{m}} = \underbrace{\ln \left( \frac{j_\text{in}}{j_\text{out}} \right)}_{\vec{d}}$$

- System of linear equations:  $A\vec{m} = \vec{d}$ .



## Systems of Linear Equations: $A\vec{m} = \vec{d}$

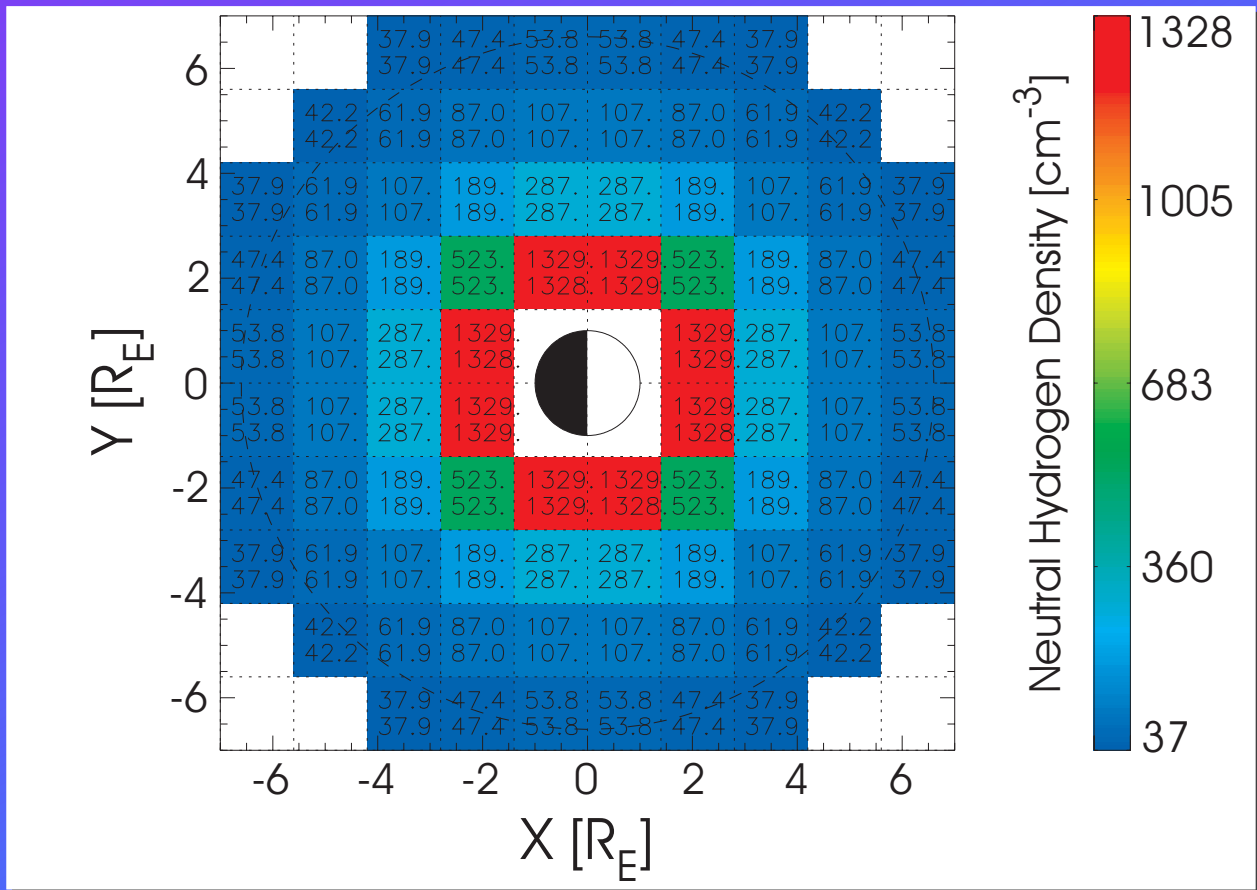
- Inversion requires **regular, square** matrix  $A$ .
- Force square matrix:  $(A^T A) \vec{m} = A^T \vec{d}$ . ( $\rightarrow$  pseudo-inverse)
- Force regularity:  $(A^T A + \lambda E) \vec{m} = A^T \vec{d}$ . ( $\rightarrow$  damping)
- Damping factor  $\lambda$  determines **resolution**.

$\Rightarrow$

$$\vec{m} = (A^T A + \lambda E)^{-1} A^T \vec{d}$$

# Forward Calculation and Inversion

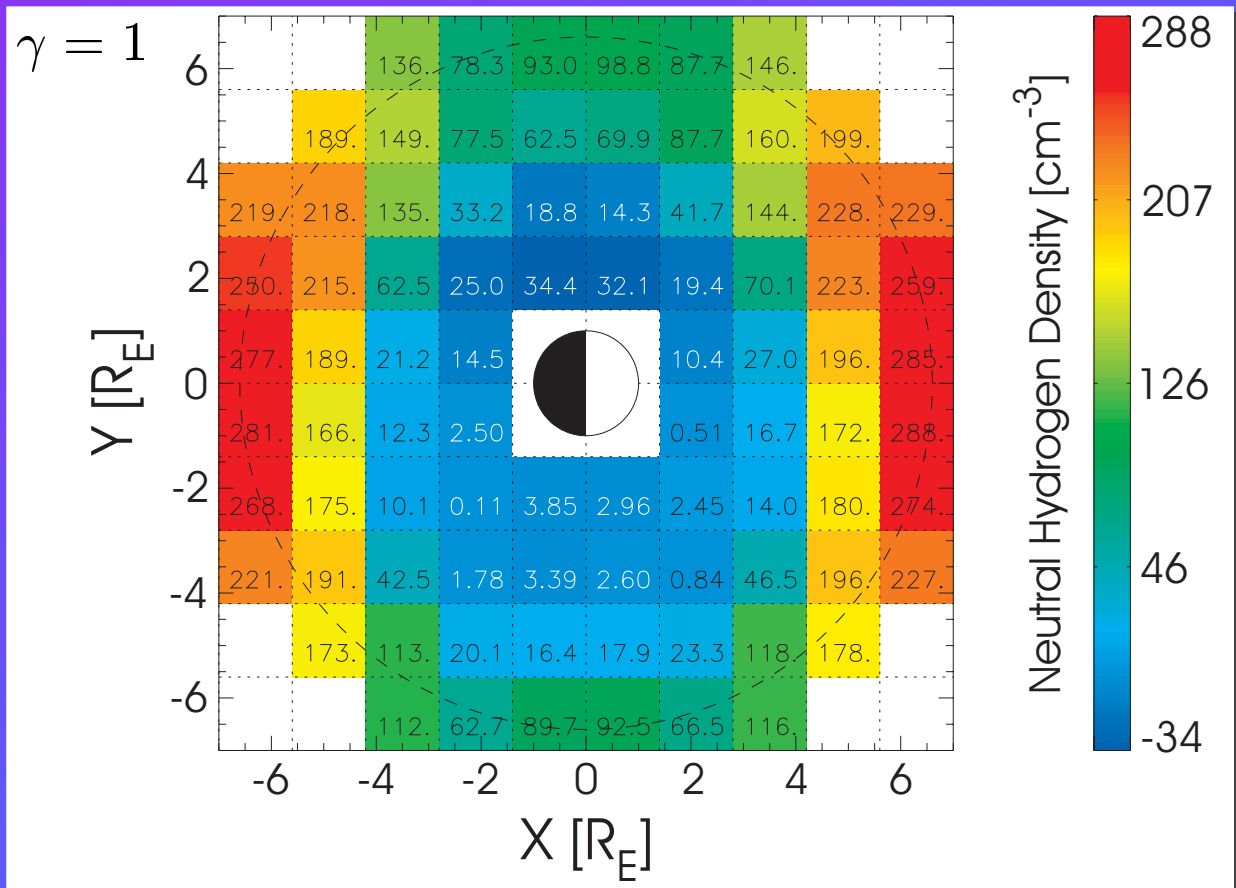
- Neutral hydrogen density: Chamberlain model with Rairden 1986 parameters.
- Forward calculation and inversion:



- Algorithm works!

# MPA-Data Inversion

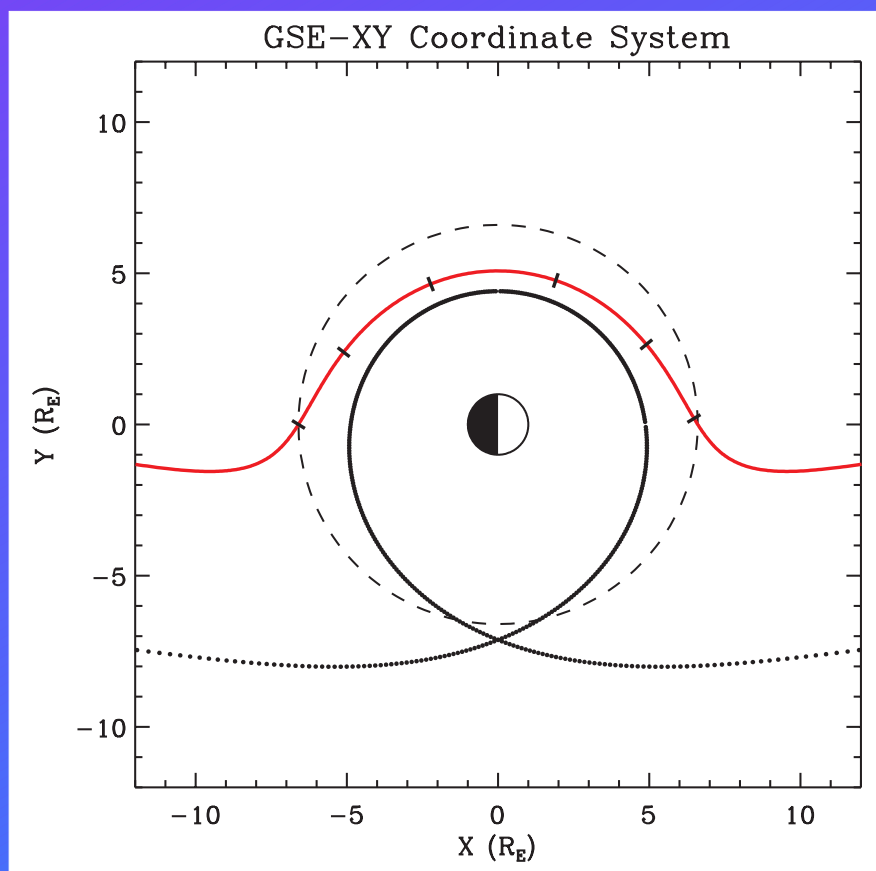
- Inversion of 1998 average proton fluxes:



- Inversion results for other years are similar.
- Inversion results for other shielding factors are similar.
- Large differences from the Chamberlain model in the near-earth region.

# The Geosynchronous Region

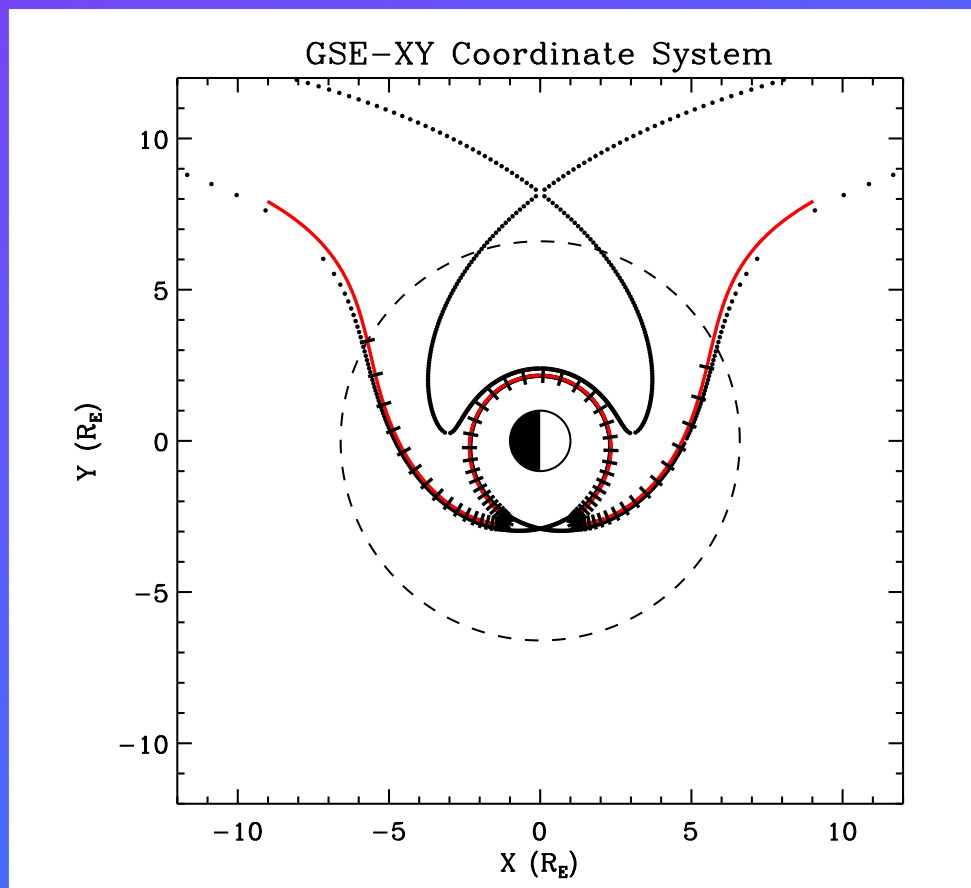
- Sampled by proton energies of tens of keV.
- Example trajectory: 10 keV @  $6.6 R_E$ , 00 LT,  $K_p = 3$ .



- Proton drift time:  $\sim 5$  hours.

# The Near-Earth Region

- Sampled by proton energies of a few keV.
- Example trajectory: 1 keV @  $6.6 R_E$ , 2200 LT,  $K_p = 3$ .



- Proton drift time:  $\sim 3.5$  days.

## Summary

- Tomographic inversion is a powerful remote-sensing tool.
- Inversion algorithm was successfully tested on a testbed database obtained by forward-modeling drifts through a Chamberlain exosphere.
- MPA-data inversion shows large differences to the Chamberlain model in the near-earth region.
- These differences are due to lower-than-expected losses of lower-energy particles that nominally drift through the inner region.
- Possible implications:
  1. Actual hydrogen density may be lower than the Chamberlain model in the inner region predicts.
  2. There may be sources within the inner region.
  3. Drift paths don't actually penetrate that deeply. (More sophisticated convection models are needed, perhaps including temporal variations.)

